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13. ABSTRACT (Maximum 200 words)

This paper describes a method of assessing military command decisionmaking using simulation experiments and dynamic modeling, along with some typical results. Our simulation studies have been carried out since 1988 in the Research, Engineering, and Systems Analysis (RESA) facility at the Naval Ocean Systems Center (now Naval Command, Control and Ocean Surveillance Center) under contract with Pacific Science and Engineering, Inc. and Sonalysts, Inc. RESA is a facility for presenting large-scale, event-driven battle simulations with realistic scenarios. High fidelity simulation is available for multiple platforms, sensors, and weapons under a broad range of tactical and environmental situations. The RESA facility has been used primarily for training naval battle force staffs and for studies of advanced sensor and weapons concepts. Our interest was to use the RESA facility for man-in-the-loop studies to determine the cognitive and decision processes of warfare commanders during battle. Our simulation experiments measured the overall effectiveness of the C^3I system with the performance of the commanders as its principal determining factor.

The aim of the research program is to improve the design of future C^3I systems by identifying and ameliorating human information processing and decisionmaking problems associated with critical battle decisions. Initial work has been in the anti-air warfare (AAW) area. Of particular concern are:

- Identification of critical information used for battle decisions;
- Specification of the time sensitivities for that critical information;
- Determination of the effects of information characteristics, such as density, consistency, ambiguity, conflict, delay, and degradation on the decision process; and
- Assessment of the role of individual characteristics and cognitive mechanisms, such as initial expectations, and tactical decisionmaking style, in producing variability in decision behavior.

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METHODS FOR ASSESSING TACTICAL DECISIONMAKING IN BATTLE[1,2]

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SITUATION DESCRIPTION

Overview of the Research Program. This paper describes a method of assessing military command decisionmaking using simulation experiments and dynamic modelling, along with some typical results. Our simulation studies have been carried out since 1988 in the Research, Engineering, and Systems Analysis (RESA) facility at the Naval Ocean Systems Center (now Naval Command, Control and Ocean Surveillance Center) under contract with Pacific Science and Engineering, Inc. and Sonalysts, Inc. RESA is a facility for presenting large-scale, event-driven battle simulations with realistic scenarios. High fidelity simulation is available for multiple platforms, sensors, and weapons under a broad range of tactical and environmental situations. The RESA facility has been used primarily for training naval battle force staffs and for studies of advanced sensor and weapons concepts. Our interest was to use the RESA facility for man-in-the-loop studies to determine the cognitive and decision processes of warfare commanders during battle. Our simulation experiments measured the overall effectiveness of the C^3I system with the performance of the commanders as its principal determining factor.

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- Assessment of the role of individual characteristics and cognitive mechanisms, such as initial expectations, and tactical decisionmaking style, in producing variability in decision behavior.

The Simulation Experimental Method. The tactical scenario under study involved the air defense of a carrier battle force against a large raid of enemy bombers carrying air-to-surface missiles. The battle force included Aegis cruisers, destroyers, and combat support ships. The principal weapon employed was the F-14D fighter-interceptor armed with modern air-to-air missiles. A hot war situation was assumed throughout. The simulation runs consisted of two hours of operational time compressed into 50 minutes of real time. Variations of the scenarios were constructed to test differing levels of the experimental variables. Detailed intelligence and instructions were provided to the commanders. Research assistants interacted with the computer system so that the commander was not required to learn simulation language or procedures. In order to standardize the scenario for the purpose of comparing the performance of different commanders, enemy actions were entirely prescripted for all simulation runs.

The Command Information–Decision–Action Process During AAW. The anti-air warfare (AAW) commander's decision environment is a complex, high tempo world based on a stream of raw and processed data inputs from a wide variety of sensors and intelligence sources, with supporting analytic and communication systems. He is assisted by a team of subordinates who carry out various complex processing tasks that refine and cleanse the data and help interpret it. The commander must integrate key information to formulate and update his tactical picture, relate this picture to anticipated events and planned responses, and make a series of decisions regarding the appropriate actions to respond to the threat. This process is a dynamic one, continually requiring adjustments as the combat scenario unfolds.

Command decisions during battle are made within a mission and organizational context of command relationships, responsibilities, and interdependencies. Decisions are often short-fused. Each decision is bounded by a limited time period for response (or decision window) during which action must be taken in order to be effective. Earlier or later action compromises effectiveness, putting the commander under great pressure to act in a timely fashion. However, timely decisions may require acting on incomplete or ambiguous information. The decision to act initiates a complex, often time-consuming implementation process involving the coordinated actions of many other actors and associated man-machine systems. As his decisions are implemented, the commander must continue to monitor the unfolding situation and assess the effectiveness of his actions in order to decide on follow-up or corrective actions.

The decision process and the decision environment are frequently less than optimal. The information flow may be sporadic or delayed. Critical data sought by the commander may not be available when he needs it. Varying amounts of spurious, ambiguious, or conflicting data may be delivered. On the other hand, his information environment may be extremely dense due to the high tempo of threat actions and processing quirks during battle. It is a challenging task for him to selectively scan, process, integrate, and interpret incoming data in relation to the Battle Force plans and mission. Naval officers bring to the battle

unique combinations of knowledge, skills, and decision abilities, so that variability among individuals performing the command decision role is inevitable. Commanders' expectations during the situation assessment process may facilitate or distort their assessments. Even among equally experienced warfare commanders, the interpretation of the data stream can result in different tactical pictures, confidence levels, and interpretations. Information characteristics, such as density, consistency, ambiguity, and delay may influence a commander's decisions in subtle ways.

METHODS FOR ASSESSING DECISION PROCESSES

Simulation Experiments. Simulation experiments are a combination of simulation technology with the experimental method. Simulation technology uses the computer to present complex, dynamically unfolding stimuli in a manner which is highly appropriate and realistic in mimicking the shipboard Combat Information Center environment. This simulation evokes the decisionmaker's "natural" information processing and decisionmaking behaviors while allowing the researchers to control a large number of theoretically or empirically less relevant factors. The decisionmaker's behavior is further elicited by the apparently normal response of the simulation to his actions. Application of an experimental perspective leads to creation of variations of the standard scenario, to manipulate hypothesized causal factors determining or impinging on the decisionmaker's behavior. The standardized scenarios may be used to expose a sufficient number of qualified decisionmakers to statistically test the influence of the factors under examination. Since we have found minimal learning effects in our battle simulations, decisionmakers may be exposed to a systematically programmed sequence of scenarios to obtain repeated measures and bolster the number of data points.

The simulation technology enables us to measure a number of process as well as outcome variables. In RESA we are able to collect on-line data on the decision process and its consequences, such as orders, object positions, and engagements. In addition, we can make audio recordings of participants as they communicate their thought processes or conduct official communications. Research personnel also record situation assessment reports and post-trial debriefings. These verbalizations can be subjected to extensive protocol analysis prior to statistical evaluation. We can obtain outcome measures (e.g., kills) by playing out the simulation until all the weapons are released and engagements are completed. We have devised and examined various measures of performance and effectiveness, encompassing the individual commander and the battle force.

Simulation experiments provide a considerable degree of control over salient variables during simulated battle decisionmaking by warfare commanders. However, the limited number of qualified subjects (warfare area experts) requires limiting each study to a few variables which can be systematically manipulated while obtaining adequate cell sizes for statistical analyses. Analysis of a larger number of variables (and levels within variables) requires that a carefully planned sequence of studies be performed. This research program has so far focused on selected information degradation conditions and their effects on the decisionmaking process. A possible future focus is testing system design concepts to ameliorate problems identified in our studies.

We have used the simulation experimental technology to study both the case of a single decision maker and multiple interacting warfare commanders. Studies of multiple commanders entail additional cost in data collection and analysis effort, but they extend the range of questions and issues which can be addressed. For example, such studies allow examination of issues in information exchange, methods for dealing with discrepancies in data interpretation among commanders, mechanisms for coordination, and influence patterns among commanders.

Dynamic Modelling. Based on empirical data collected during simulation experiments, a model of warfare commander decision processes is being used to test the key decisions, associated variables in the decision process, their causal and quantitative relationships to each other, and their relationships to system (battle force) outcomes. The model has two levels of analysis encompassing hypothetical constructs from relevant theory:

- The macro level, in which the interacting decisionmaker carries out his mission responsibilities within the context of the multi-person, highly structured, hierarchical organization of the naval battle group; and
- The micro level, in which the warfare commander functions as the decisionmaker responsible for processing information and solving problems in order to arrive at action decisions in his warfare area.

The model uses quantitative data from the simulation experiments, fleet exercise evaluations, and other empirical studies to precisely define the relationships among key factors operative in the command decisionmaking process. The model helps us understand how data flows, time phasing, interpretation mechanisms, problem solving processes, cognitive factors, and interpersonal factors affecting the decision processes of warfare commanders. The empirically defined relationships among factors in the model provide an unambiguous framework for deriving testable research questions, hypotheses, design principles, and guidelines for improving C^3I support for the decision process. A select few of these derivations will be further tested in man-in-the-loop studies. Thus, use of the model helps guide studies of the decision process.

TYPES OF RESULTS

Use of the simulation experimental method and dynamic modelling has produced several insights into the command decision process.

Process Analysis. By performing protocol analysis of the commanders' concurrent verbalizations about their decision processes during the simulation experiments, we have been

able to track their use of battle information in making launch decisions. A clear pattern in information usage emerges when the battle is divided into phases defined by scenario events, as shown in Figure 1. Considering only threat information, Raid Count was used most across all battle phases, peaking in the Late phase. Use of Intelligence Reports and Track Localization information varied most across battle phases, both showing a pattern of initially high usage that decreased steeply as the battle progressed. Electronic Support Measures (ESM) and Track Speed information were used least often, with ESM being most frequently used early in the battle and Track Speed

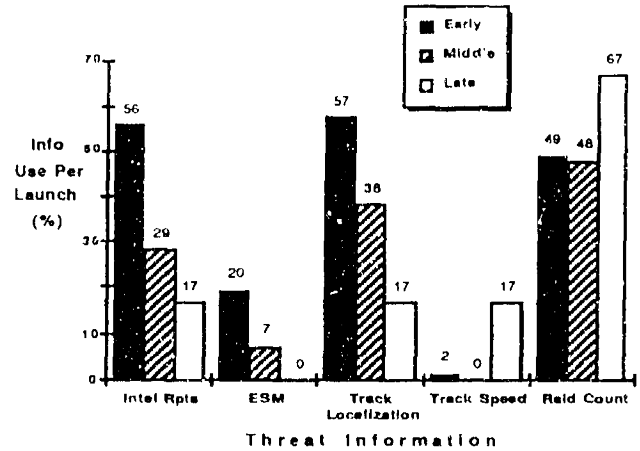

Figure 1. Use of threat information across battle phases

late in the battle. From the standpoint of optimal decision making, the observed pattern of information usage drastically underemphasizes intelligence information early in the battle, ESM throughout the battle, and track information in the middle and end phases of the battle. It appears that graphically-presented data is overemphasized and abstract alphanumeric data is underemphasized or poorly integrated into the tactical picture. Our analysis suggests the possibility that improved presentation of relevant tactical data could be used to change the warfare commander's pattern of usage to achieve improve battle outcomes.

General Factors. Our focus has been on measuring the influence of factors that exert strong general effects on the decision process of the typical commander. We have found that short interruptions in the flow of tactical information have highly consequential disruptive effects on launch decisions, although commanders have little awareness of the alteration in their behavior or its ultimate impact on system performance. (See Figure 2.) In examining decisions to launch interceptors, interrupts during the early phase of the battle (before the main body of the enemy was detected) were found to significantly affect outcomes (i.e., kills). Since commanders were waiting for positive indications of the location of the main raid, greater interruption caused them to delay their decisions to launch the bulk of their assets until definite raid indications were seen. Those delays were critical to system outcomes, because they reduced the possibility of successful completion of the intercepts. Although the number of launches were equivalent in the middle and late phases, the effects of the delays in the early phase were not able to be offset by later launches due to the geometries and time requirements.

Individual Factors. Initial studies suggested apparent stylistic differences in decisionmaking that we have defined as spontaneous vs. deliberative. Spontaneous commanders rely more on the emerging graphical tactical picture, with less anticipatory behavior and using fewer kinds of supplementary information, such as ESM, in making launch decisions. Their launch decisions result in relatively delayed resource commitment and more assets left unused on deck. Deliberative commanders use more kinds of information and display a more anticipatory orientation, committing their resources earlier and employing more of their available resources against the threat. (See Figure 3.)

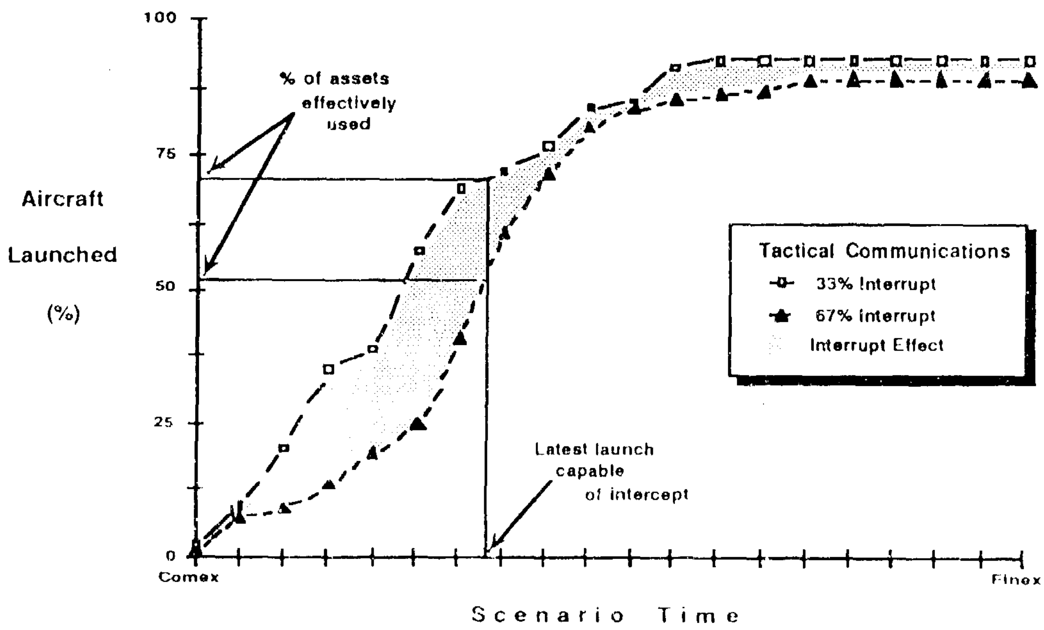

Figure 2. Anti-air warfare commander lag in early resource commitment under tactical data interrupt

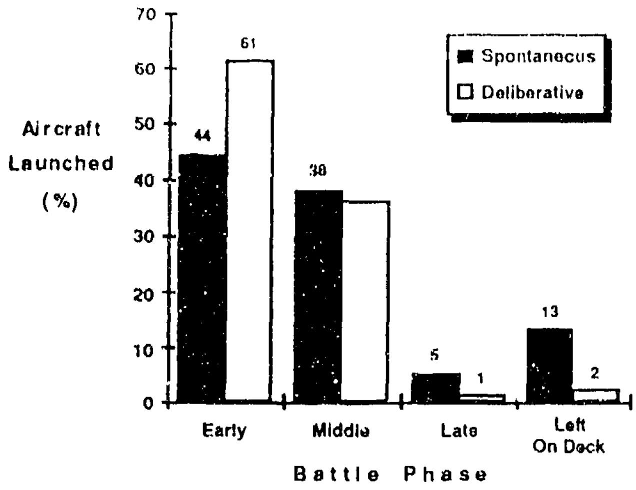

Figure 3. Influence of decision style on launch profile

CONCLUSIONS

Command decisionmaking is an extremely challenging set of phenomena to study. In its natural setting, decisionmaking is a complex, one-time event. It is performed by relatively few people whose extensive experience and knowledge are bases for rare expertise. It is largely an internal process whose most important mechanisms are probably not appreciated by those who do it best. It is likely influenced by factors from many domains, ranging from task and information characteristics to organizational structures and cognitive processing mechanisms. To make these phenomena tractable requires a method that can enable quantification in the laboratory without losing its essential nature.

A critical aspect of the nature of command decisionmaking is the dynamic information environment. To attenuate the information flows would fundamentally change the nature of any decisionmaking. To eliminate or minimize the experience and knowledge brought to the task by its practitioners would alter the phenomena in unknown ways. To reduce the stress or tempo or ambiguity or uncertainty would call into question the validity and generalizability of any findings. The simulation method is essential to maintaining these critical aspects of decisionmaking phenomena.

Systematic analysis requires careful manipulation of factors hypothesized to have an influential role. The complexity and subtlety of the impacts and interactions among these factors dictate a high degree of control, using simulation experimental designs that hold most factors constant while varying a few. The most important factors can be explored using dynamic modelling to test additional levels and combinations. Again, the simulation technology allied with an experimental paradigm and modelling tools provides a workable approach.

Any research method imposes constraints on the conceptual understanding of the behavior under study. Previous static approaches led to a conceptualization of decisionmaking as occurring at a single point in time. The simulation experimental method allows a fundamentally different picture of tactical decisionmaking to emerge than has been understood previously. Tactical command decisionmaking should no longer be viewed as a momentary calculation of expectancies or comparison of options. Rather it should be understood as beginning with the tactical planning process, when anticipated events are defined and response strategies evaluated and laid out along a timeline in coordination with other interdependent members of the command team. A later phase of the same decision process is the assessment of the unfolding situation in relation to the previously formulated plans. This assessment may require weighing the appropriateness of executing planned responses as opposed to modifying the planned responses to suit circumstances which deviate from those anticipated during planning. The decision process continues beyond the "decision point," into the execution process, when feedback may dictate decisions to take corrective or additional actions. In essence, the entire definition of decisionmaking should be shifted from a momentary event to a process over time. This opens new vistas for understanding the influential factors and mechanisms and how such factors can be controlled or brought into the service of improved decisionmaking.

Command decisionmaking is an integral component of weapon systems performance. That decisionmaking is based on C^3I systems that provide supporting information and assistance in processing it. There is a growing realization among military systems designers that a critical amount of the performance anticipated during design fails to occur when systems are fielded due to inadequate consideration of the users' needs and capabilities. Our findings show that commanders do reasonably well using a portion of the available data (primarily radar), but other data (i.e., track speed, ESM) is not integrated and used effectively. The causes of this distortion in information use may be organizational as well as cognitive and must be further investigated. Modern thinking recognizes the human user as an integral component of the system and a key determinant of its performance. Efforts to improve the design of future C^3I systems require better understanding of the systemic causes of variability and degraded human decision performance. The simulation experimental methodology and dynamic modelling tools provide a much needed capability to measure complex decision behavior relevant in military operational settings. The NCCOSC research program is plying these methods as tools for producing insights and testing solutions that can be used to improve decision effectiveness in critical operational situations.

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1 Presented at the 9th Annual Decision Aids Working Group Conference, Monterey, CA, 8-9 June 1992.

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